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Phased Array Antenna Testbed Development at the NASA Glenn Research Center

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Abstract

Ideal phased array antennas offer advantages for communication systems, such as wide-angle scanning and multibeam operation, which can be utilized in certain NASA applications. However, physically realizable, electronically steered, phased array antennas introduce additional system performance parameters, which must be included in the evaluation of the system. The NASA Glenn Research Center (GRC) is currently conducting research to identify these parameters and to develop the tools necessary to measure them. One of these tools is a testbed where phased array antennas may be operated in an environment that simulates their use. This paper describes the development of the testbed and its use in characterizing a particular K-Band, phased array antenna.

1. Introduction

Several electronically steered, phased array antennas have been utilized in experimental communication systems by investigators at the NASA Glenn Research Center. Historically, the antennas have been mounted on airplanes or on mobile terrestrial units. The antennas were required to track geosynchronous satellites, while the platform was in motion, in order to complete a voice/data communication link [1–3]. In these applications, the scan angles and the scan rate of the antenna beam required to maintain the link were relatively small. The results there led to the consideration of phased array antennas in systems communicating with Low Earth Orbiting (LEO) platforms. Here, an antenna must scan to wider angles and steer at a higher scan rate in order to maintain the link. Furthermore, a higher data rate is desired in order to transfer as much information as possible in a single pass of the platform. The use of a phased array antenna in such an application introduces characteristics that affect the link and must be studied and understood before adopting the approach. To assist in the study, GRC has pursued the development of a testbed in which a communication link, utilizing a scanning phased array antenna, can be simulated.

Interest in the development of the testbed began in year 2000 as GRC anticipated the delivery of a K-Band transmit phased array antenna [4]. The performance of the antenna was to be verified in laboratory testing at GRC before being used in the flight segment of a planned LEO communication experiment. A feasibility study was performed [5] to determine if the specified testing requirements were best achieved by building a new test chamber or by refurbishing an existing one. The options presented by the study were not accepted and thus efforts were directed to incorporating the testbed within the GRC Far-Field Antenna Range Facility [6]. The technical difficulties associated with completing the K-Band antenna were insurmountable and the experiment was cancelled. The work for the testbed development proceeded however, as other phased arrays were identified as test subjects for study of the anticipated communication link issues. This report reviews the work with the GRC Far-Field Antenna Range Facility.

The Far-Field Antenna Range Facility was originally developed to investigate small, prototype microwave antennas such as horn antenna and individual array elements. The short range distance and the limited instrumentation available were adequate to meet those needs. In order to accurately measure the larger phased array antennas being considered, the size and the quality of the quiet zone needed to be known. Therefore a measurement program, described below, was carried out to characterize the range itself. Based on the findings of the measurements, improvements were made to the layout of the range. The pattern measurement capability of the range was retained in order to evaluate the basic radiation performance of the antenna. Examples of this capability are given for a 91 element, 20 GHz receive array developed by Boeing for the Rome Lab/MILSTAR

Integrated Circuit Active Phased Array (ICAPA) program [7]. The first communication system experiment to be implemented in the testbed was for bit-error-rate (BER) testing of the link as a function of antenna scan angle. The study of the behavior of the link as the array is switched between scan angles was also implemented. The configuration for these tests is given and results for the ICAPA antenna presented. Finally, concluding comments are made about the experiences with this testbed and ideas for future experiments are offered.

2. Range Evaluation and Preparation

One of the early topics of discussion, as plans for the testbed were being made, was the importance of performing a field probing of the chamber to be used. The decision was made to proceed with the design and development of a Range Probing System (RPS) even though it was unclear where the testbed would be located. The RPS was to provide sufficient data so that the size and quality of the test zone could be determined. The data would also be used to identify the chamber characteristics that affect the test zone quality and lead to efforts for improvement. Furthermore, the data could be provided to interested principal investigators to be included in their final analysis of experiment data from the testbed. In addition, the RPS had to be portable, since the testbed location was not known, flexible, so that it could be used in other GRC antenna ranges, and reconfigurable, so that it could support other experiments.

The RPS is based on three primary subsystems consisting of a probe positioner, RF instrumentation and software control. The positioner subsystem is an x-y planar scanner with supporting hardware for alignment and positioning of an RF probe. The RF instrumentation subsystem includes the transmitter and receiver that generate and detect the test field. The software control subsystem coordinates positioner movement with operation of the RF instrumentation and records the data.

The scanner is a set of Velmex, Inc. Bi-Slide™ assemblies arranged in an inverted-T configuration to provide up to five feet of probe travel in both the horizontal and vertical direction. The horizontal Bi-Slide™ assembly, a tandem pair consisting of a driven slide and follower slide, carries the single vertical slide. The vertical slide contains the carriage assembly to which the probe is mounted. The custom bracket, attaching a waveguide probe to the carriage, also provides for an alignment laser. The laser, recessed behind the waveguide flange, remains in place during the scans, enabling periodic alignment checks. A Velmex VP9002 programmable motor controller provides the control of the stepper motor drives.

The RF instrumentation, as shown in Figure 1, is based on the Agilent (HP) 8510B Network Analyzer. Use of the 8511A Frequency Converter restricts the upper frequency limit to 26.5 GHz; however, this was sufficient for the originally planned K-Band tests. The external amplifier is used to provide sufficient transmit power levels. The choice of transmit antenna and probe are application dependent but use of a standard gain horn and open ended waveguide is typical.

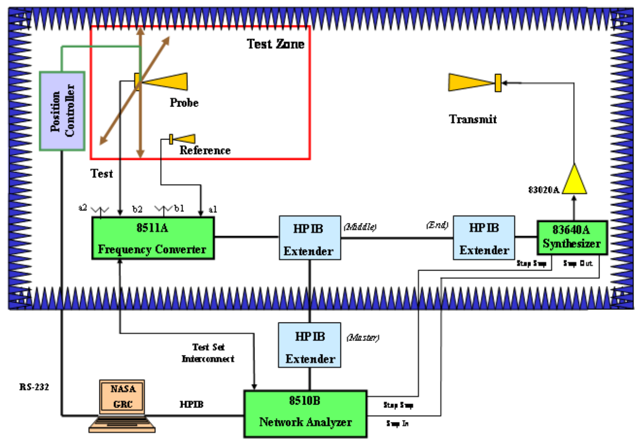


Figure 1 – RF Instrumentation for the Range Probing System.

The software control subsystem consists of a Windows 98 platform communicating with the scanner controller via a RS-232 interface. A General Purpose Interface Bus (GPIB) is used for communication with the Network Analyzer, which subsequently controls the synthesizer and frequency converter. Bus extenders are used if required by the range distance. Two software applications were written in C++ for the subsystem. The first is a scanner utility used during the mechanical boresight alignment procedure. Upon alignment, a coordinate reference is established for the scan at the boresight location. The second is then used to perform the scan. Scan variables that are built into the application include RF frequency of the test, scan plane size, vertical or horizontal raster pattern and sample spacing.

Completion of bench testing of the RPS coincided with the decision to locate the phased array testbed in the Far-Field Antenna Range. Figure 2 shows a view of the chamber at that time. Some of the improvements necessary to the layout of the chamber were obvious without the use of the scanner. Others became evident with the use of the scanner.

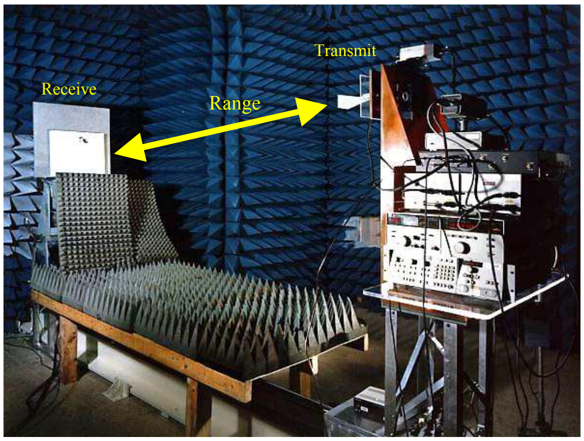
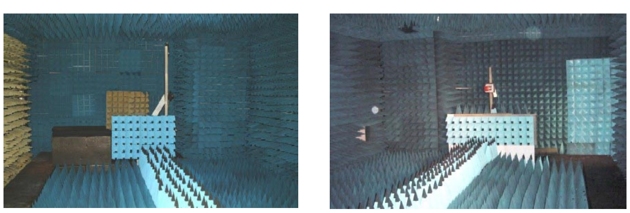


Figure 2 – GRC Far-Field Antenna Range prior to use as a Phased Array Testbed.

In summary, the range distance was increased to 24 feet, the maximum available within the existing room. Stable supporting structures, for the antennas and associated equipment, were built at each end the chamber. These structures were placed behind absorber baffles to reduce test zone interaction from reflections. The floor was treated with pyramidal absorber with the exception of an absorber walkway that was installed to ease personnel access to equipment. An interlock system was installed on the chamber doors for personnel safety and to preserve test integrity during unattended experiments. Following these changes, the chamber, with the scanner installed, appeared as in Figure 3.



South end– with probe **North end – with source**

Figure 3 – GRC Far-Field Antenna Range modified for the Phased Array Testbed.

Probe data was collected over the full range of the scanner in a vertical raster pattern. A number of K-Band frequencies were used at several range distances. A Scientific-Atlanta, Model 12A-18, Standard Gain Horn was the source antenna and a section of WR-42 waveguide was the probe. Sample spacing was 0.25 λ at each frequency. The vertically polarized results at 20 GHz are presented in Figure 4. Only a subsection of the completed scan is shown.

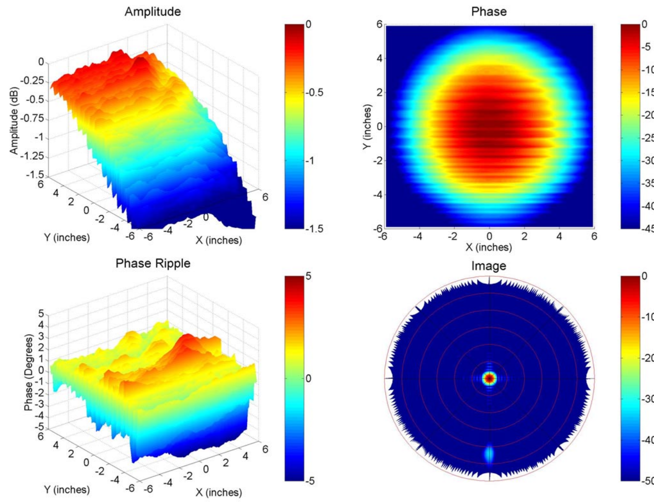


Figure 4 – GRC Far-Field Antenna Range as Phased Array Testbed, Probe Results at 20 GHz.

The quiet zone center is obtained by a quadratic best fit to the measured phase and placing the center at the maximum. Doing so results in the slight difference in the location of the maximum of the amplitude data and the phase data. This is likely due to a small (~1°) pointing error in the transmit horn. Using a 1 dB amplitude taper and a 22.5° phase taper criteria, the test zone cross section is approximately a 10 inch diameter circle. Removing the quadratic from the phase data leaves the phase ripple, which is also shown. The small level indicates that there is very little clutter remaining in the chamber. Further data processing produces the Far-Field Antenna Range image, shown in Figure 4, that reinforces this conclusion. Recognizing the source antenna at the center of the image, only one source of clutter appears down to the –50 dB level. This occurs due to the reflection from the top of the absorber panel in front of the scanner (see Figure 3). The probe data established the far field conditions of the Far-Field Antenna Range when being used as the phased array testbed. The antennas that were planned for use in the testbed could be accommodated.

As mentioned previously, the Far-Field Antenna Range Facility had been used to obtain antenna patterns only. To maintain this capability, as well as provide for the communication system experiments, a testbed configuration assembly was developed. This assembly enables the integration of system test hardware with the core antenna measurement hardware. The actual system test hardware configuration varies depending on the test required. For example, Figure 5 shows the testbed configuration assembly interfacing a BER test for the ICAPA antenna with the core system. The core antenna measurement system is shown lightly shaded with the configuration assembly within the heavy outline. The BER test equipment is outside of the shaded region but utilizes some core equipment that is made available by the testbed configuration assembly. Thus, the range is readily operated for both purposes. This feature provides an advantage for system test implementation in that evaluation of the antenna system can easily be done at any time, to determine the antenna system operational integrity.

The antenna measurement system is used prior to system tests to verify that the antenna is operating correctly and to collect detailed pattern data. For this use, the testbed configuration assembly provides the option that enables the receiver to be used with either a frequency converter or external mixers. Once antenna tests are completed, the configuration assembly provides a transfer mechanism for RF signals via switches SW1 and SW2. All selection options are handled by a throw of a switch inside the range control room. Therefore, once initial setup of both systems is completed, timely transitions that minimize disturbances to the equipment and chamber characteristics can be achieved.

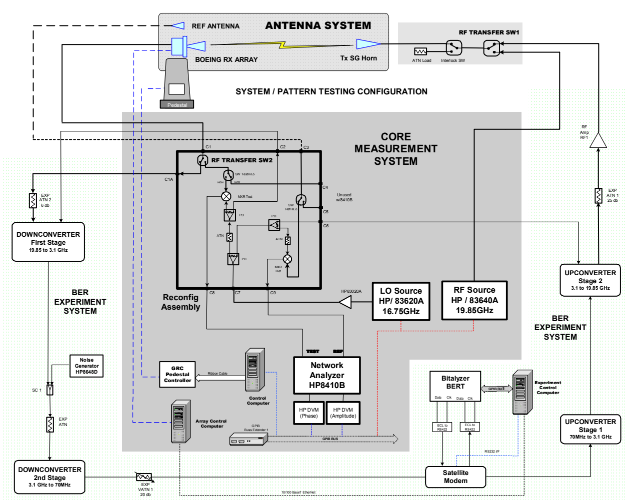


Figure 5 – Equipment Configuration for the Phased Array Testbed.

3. Pattern Tests

The first antenna to be studied using the testbed was the 91 element, 20 GHz array developed by Boeing for the Rome Lab/MILSTAR Integrated Circuit Active Phased Array (ICAPA) program [7]. The antenna, shown in Figure 6, is described by the design objectives listed in Table I.

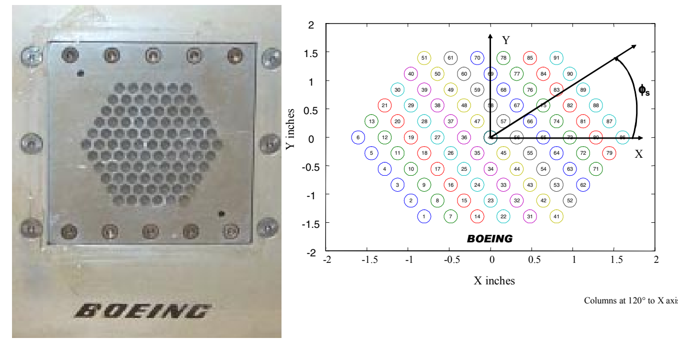


Figure 6 – The Boeing 20 GHz ICAPA Antenna.

Table I. ICAPA Receive Antenna Performance Goals

Performance Parameter	Goal
Center Frequency	20.7 GHz
Bandwidth	±500 MHz
Scan Requirement	±70° cone
Grating Lobes	None in visible space
G/T (at broadside)	–11 dB/K nominal
Polarization	RHCP
Pointing Accuracy	¼ beamwidth

A complete set of magnitude and phase patterns of the antenna were measured at the carrier frequency of the systems test, 19.85 GHz. The magnitude patterns, shown in Figure 7, were taken with a linearly polarized source antenna. The phase patterns are not shown for brevity. One of the characteristics of the antenna that is revealed by the patterns is the scanning accuracy at the wider scan angles. One possibility for the source of this error was the phase taper in the test zone. At boresight, (azimuth = 0°), the phase taper is not significant across an aperture of this size. However, the antenna was mounted forward of the center of rotation, which put the aperture near the edge of the test zone at the larger angles. As shown in the probe data, the phase taper at the edge was near 22.5°. Since this antenna utilized 4-bit phase shifters, the phase error at the edges was equivalent to one phase state which could contribute to the error. Computer modeling of the antenna however, revealed the pointing error was a direct result of the quantization error of the phase shifters [8]. Thus, the actual performance of the antenna was being simulated accurately in the testbed.

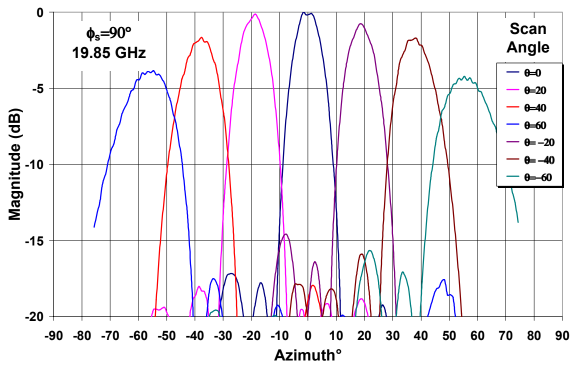


Figure 7 – ICAPA Antenna Patterns as Measured in the Phased Array Testbed.

4. Bit Error Rate Tests

Typical RF patterns provide limited insight into the operation of a phased array antenna in a communication system. To further measure the expected operational performance, the phased array testbed is configured to include the data channel and bit error rate degradation is determined. The most dominant effect of bit error rate (BER) degradation on wideband phase array antenna links is caused by the limitations imposed by digital phase shifters. In a K-band phased array system, digital phase shifters are incorporated instead of true time delay devices. The digital phase shifters are limited to a 2π phase setting. This fixed modulo 2π restriction, in addition to delay across the aperture, can induce intersymbol interference (ISI), contributing to an increased BER. The effect of ISI on the BER increases with higher symbol rates, wide scan angles, and number of elements. As the symbol rate becomes an appreciable percentage of the carrier rate, the ISI begins to significantly affect the demodulator's ability to accurately estimate the value of the transmitted bit. At low carrier frequency to symbol rate (Fc/Rs) ratios, a significant energy loss, potentially causing loss of synchronization, may occur. Modeling conducted at GRC indicated as much as a 3-4 dB loss for high rate modulated data operating at K- and Ka-band for an Fc/Rs = 10. These losses are greatest for high E_b/N_0.

To observe the degradation caused by wide scan angles, the BER of the system was measured with the array scanned off boresight and compared to the BER measured with the modem IF only (back-to-back) and at boresight. Noise added to the system at IF, prior to the demodulator, varies the E_b/N_0 and is used to obtain a system curve. For a 622 Mbps data rate, the 1-1.5 dB shift in BER shown in Figure 8, was observed between a 60° scan angle and a 0° scan angle [9].

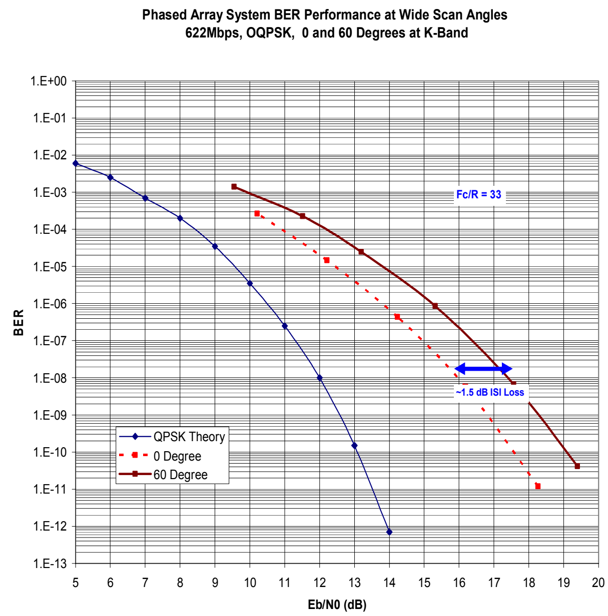


Figure 8 – Wide Scan Angle BER Performance at 622 Mbps.

5. Transient Tests

The transient effects of beam switching on a phased array based communication system are measured under continuous wave (CW) excitation [10], and with a low and high data rate synchronized signal. To measure the BER performance associated with beam-switch events, the data path is first synchronized at a specific signal level. The beam is then commanded to switch in one degree increments from a center scan angle approximately 500 times. Each time the beam is scanned, the phase settings calculated by the beam steering controller (BSC) for each of the eleven rows are loaded into the shift registers in the phased array. A hardware transition signal (marker signal) is sent from the BSC, commanding the phased array to shift the data from the shift registers to the phase shifters. Errors are recorded by the bit analyzer. The hardware transition signal is connected to the marker input on the bit analyzer, allowing for time correlation of the beam switch with the bit errors.

The data are analyzed by locating the bit errors measured with respect to the marker signal. Results for 5000 transients at a high data rate (622 Mbps) are shown in

Figure 9. Results from this case indicate an increase in bit errors associated with the digital clocking pulses that occur with transfers of data from the BSC to the digital electronics of the phased array and at the point when the phase shift occurs. Data coding and/or filtering may compensate for this effect if properly designed. A potentially more serious effect is the loss of receiver synchronization with the communications signal due to the transients. During this testing, there was no loss of receiver synchronization.

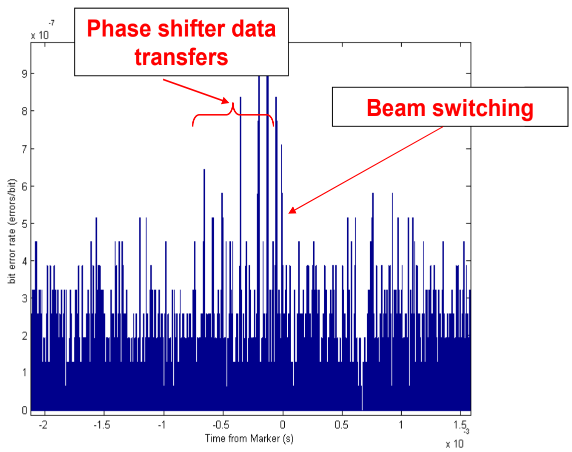


Figure 9 – Phase Shift Transient Bit Error Results

6. Conclusion

This paper has described the effort at the NASA Glenn Research Center to provide investigators with a fundamental testbed for study of the use of phased array antennas in communication systems. The testbed allows communication links to be simulated and provides the versatility to enable a range of communication tests to be performed. Thus far, BER tests have been implemented to study the effects of digital phase shifters and the transient effects of beam switching. Additional tests, such as BER with a scanning phased array antenna in a simulated LEO communication system, are being considered. In LEO systems, phased array antennas could be used in the ground segment, the flight segment, or both. Therefore transmit as well as receive antennas will be studied. For the testbed, the positioner has to be interfaced with the phased array controller to accommodate this test. Furthermore, current collaborative efforts with external organizations are expected to lead to use of the testbed for investigations with new, higher data rate, multibeam phased array antennas in years 2003 and 2004.

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13. ABSTRACT ***(Maximum 200 words)***

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